Standard Library Improvements

Chapel Team, Cray Inc.

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Outline

- Standard Library vs. Package Modules
- Reflection Library Module
  - Querying Function Resolution
  - Inspecting Fields
- Improvements to the Random Standard Module
- JAMA: Linear Algebra module
- FileSystem/Path Module Improvements
- I/O Improvements for JSON
- Other I/O Improvements
- Spawn Module Improvements
- Other Library Improvements

Standard Library vs. Package Modules

Libraries vs. Packages: Background & This Effort

Background:

- Most user-facing libraries we've distributed have lived in one directory:

  `$CHPL_HOME/modules/standard/`

This Effort:

- Over time, it's seemed that we have two classes of standard modules:
  - standard library modules
    - those that any Chapel implementation ought to support
    - e.g., 'Math', 'FileSystem', 'Reflection', …
  - package modules
    - those representing community codes or optional features
      - e.g., 'FFTW', 'LAPACK', 'HDFS', …
      - ultimately these should be managed by a distributed package manager
    - we've also moved some immature libraries here for the time being
      - e.g., 'Sort', 'Search', 'Norm', …

Libraries vs. Packages: Status and Next Steps

Status:

- Split standard modules into two directories, along with their docs:

  libraries: `$CHPL_HOME/modules/standard`

  - see http://chapel.cray.com/docs/latest/modules/modules.html

  packages: `$CHPL_HOME/modules/packages`

  - see http://chapel.cray.com/docs/latest/modules/packages.html
- Compiler populates module search path with both directories

Next Steps:

- Improve immature packages and promote to standard library
- Create a distributed package manager (see “Ongoing Efforts” slides)

Reflection Library Module

Reflection: Background and This Effort

Background:

- Chapel already supports generic programming:
  - where clauses, type functions, param functions, and param for-loops
- Yet, it can also be useful to make explicit queries
  - about procedures or methods that are available
  - about fields in records or classes
- Such introspection has proven valuable in C++
  - SFINAE and enable-if in C++
- Chapel's internal modules already make such queries
  - but not in ways that were intended for end-users

This Effort:

- Provide user-facing introspection in a new 'Reflection' module
  - inspecting which procedures or methods are available
  - inspecting fields in records or classes

Reflection: Querying Function Resolution

Can Resolve: Motivation and This Effort

Motivation:

- Suppose we're writing a sorting library
  - Uses a *compare* routine, where *compare*(a,b) returns an int that's…

    < 0 if a < b

    == 0 if a == b

    > 0 if a > b
- For usability reasons, we would like the library to
  - optionally allow *compare* to be written as a method
  - fall back on calls to < if no *compare* method/function is provided

This Effort:

- Adds *canResolve* and *canResolveMethod* functions

Can Resolve: Library Example

```
use Reflection;

private proc do_compare(a, b) {
  if canResolveMethod(a, "compare", b) {
    // use a.compare(b) if possible
    return a.compare(b);
  } else if canResolve("compare", a, b) {
    // if not, use compare(a,b)
    return compare(a, b);
  } else {
    //  otherwise, fall back on a version using <
    if a < b then
      return -1;
    else if b < a then
      return 1;
    else return 0;
  }
}
```

Can Resolve: Usage Example

```
record MyRecord {
  var x:int;
}

// Client of sorting library could provide
// any or all of these comparison routines.
proc MyRecord.compare(b: MyRecord) {
  return this.x - b.x;
}
proc compare(a: MyRecord, b: MyRecord) {
  return a.x - b.x;
}
proc <(a: MyRecord, b: MyRecord) {
  return a.x < b.x;
}
```

Can Resolve: Impact, Status, and Next Steps

Impact:

- Enables generic libraries to respond to what functions are available

Status:

- Implemented, documented, fully functional

Next Steps:

- Replace current internal uses of ‘tryToken’ with ‘canResolve’
  - this was the previous (and weaker) internal means of making such choices
- Get user feedback on ‘canResolve’

Reflection: Inspecting Fields

Inspecting Fields: Motivation

Motivation:

- Suppose that we're writing an I/O library with a particular format, e.g.
  - JSON
  - XML
  - YAML
  - BSON
  - MessagePack
  - Protocol Buffers
  - Apache Thrift
- For usability reasons, want the library to work with any record or class

This Effort:

- Adds field introspection routines
  - *numFields, getFieldName*, *getField*, *getFieldIndex*, *hasField*

Inspecting Fields: Library Example

```
use Reflection; use Types;

private proc do_outputYaml(obj:?t, indent:string) {
  for param i in 1..numFields(t) {      // param loop over fields
    var field = getField(obj, i);       // query value of ith  field
    var fieldName = getFieldName(t, i);  // query name of ith field
    if isString(field) || isNumeric(field) {
      // Output numbers and strings directly
      writeln(indent, fieldName, ": ", field);
    } else if isRecord(field) || isClass(field) {
      // Recurse to output a record or class.
      writeln(indent, fieldName, ":");
      do_outputYaml (field, indent + "    ");
    } else compilerError("unhandled type ", field.type:string);
  }
}
proc outputYaml(obj) {
  writeln("---"); do_outputYaml(obj, ""); writeln("...");
}
```

Inspecting Fields: Usage Example

```
var r = new Invoice(number=22, total=135.17,
                    new Customer("Dorothy", "Gale"));
outputYaml(r);

record Customer {
  var first_name:string;
  var family_name:string;
}
record Invoice {
  var number:int;
  var customer:Customer;
  var total:real;
}
```

```
---
number: 22
customer:
    first_name: Dorothy
    family_name: Gale

total: 135.17
...
```

Inspecting Fields: Impact, Status, and Next Steps

Impact:

- Enables generic libraries to adapt to fields in records and classes

Status:

- Implemented, documented
- *getField* does not currently return a mutable value
  - primitive can be used for now as a workaround
  - *getFieldRef* implemented but didn't make it into v1.13 (on master now)

Next Steps:

- replace uses of primitives in ChapelIO with Reflection module routines
- consider changing these functions to methods / type methods

Improvements to the Random Standard Module

Random: Background

- **<= 1.12 only had NPB Random Number Generator (RNG)**
- **NPB RNG has issues**
  - it's a 46-bit Linear Congruential Generator (LCG)
  - it only supports generating real(64), imag(64), complex(128)
  - it's implemented in terms of double-precision arithmetic
    - i.e., has lower than ideal performance if converting reals to integers
  - it's not suitable for Monte Carlo*
  - it fails 41/144 statistical tests in TestU01's Crush suite
- **Yet, the NPB RNG supports *jump-ahead***
  - supports deterministic parallel RNG use cases
- **Have long intended to address these issues**
  - Users have requested better Random support as well

* = see Click, Kaminski, and Liu, "Quality of random number generators significantly affects results of Monte Carlo simulations for organic and biological systems"

Random: Some other RNGs

- **Mersenne Twister**
  - popular
  - used in Python
  - we didn't find a version that supported jump-ahead that we liked
    - came with disclaimers
    - raised licensing challenges (GPL, vague/missing licenses)

- **PCG: Permuted Congruential Generator**
  - reasonably new
  - supports jump-ahead
  - simple implementation
  - C implementation available with permissive license (Apache)

Random: This Effort

- **Implemented PCG RNG purely in Chapel code**
  - it was simple enough not to require wrapping the C library
  - main PCG RNG has 64 bits of state and generates 32 bits at a time
  - generate >32 bits by splicing RNGs with different increments
  - Adds functionality to the C PCG implementation
    - generates real values (via multiplying by 2**-64)
    - generates bounded integer values in way that supports jump-ahead
- **Refactored Random standard module**
  - Parallel *RandomStream* available with either NPB or PCG RNG
  - PCG is now the default
  - Low-level PCG module is also available, providing interface like C's
- **Added new functionality**
  - *shuffle*, *permute*, generate random integer
- **Documented *RandomStream.iterate***

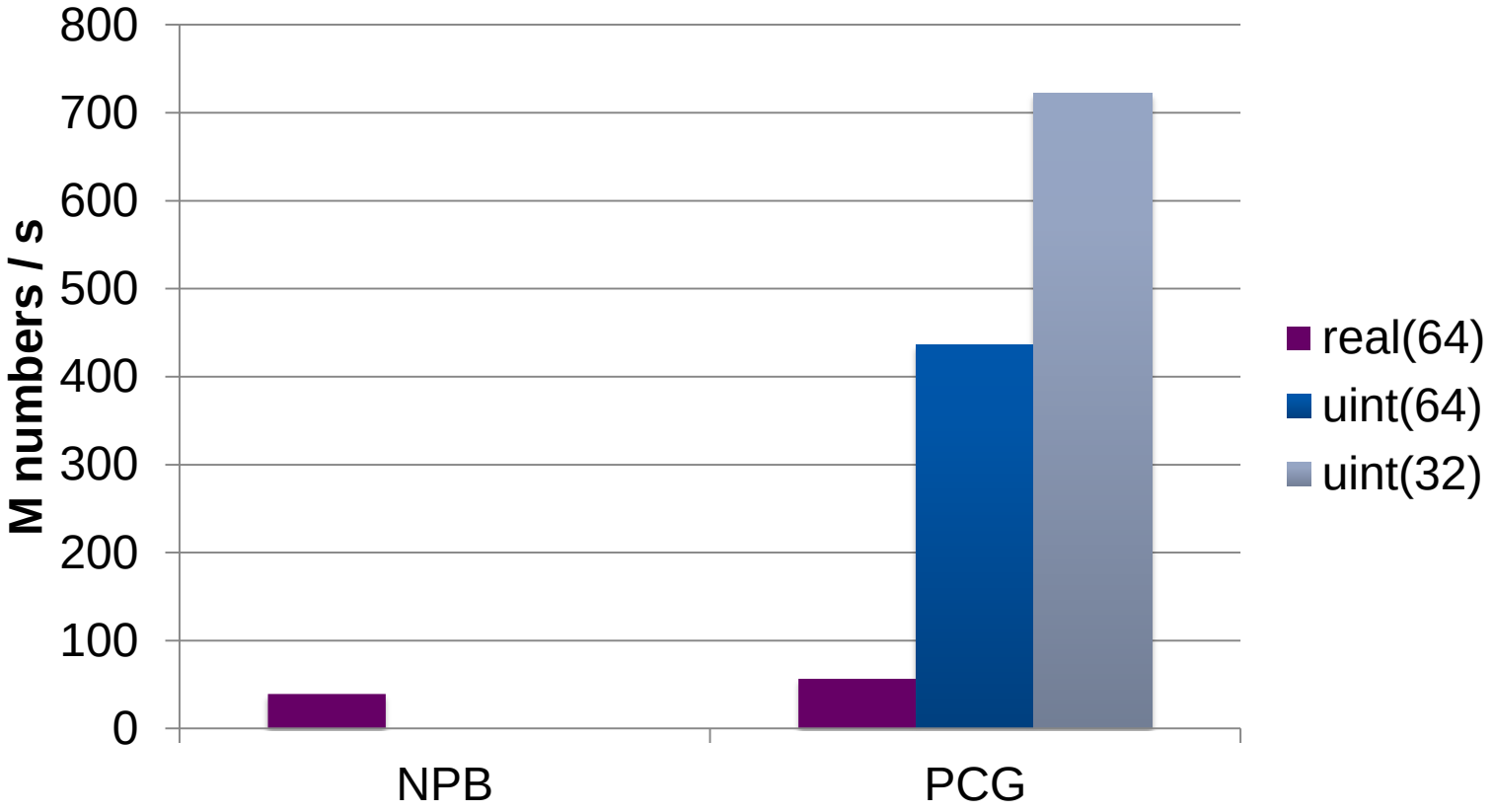
Random: Impact

- **Tested statistical properties with TestU01's Crush suite:**
  - NPB failed 41/144 tests for real(64)
  - PCG passed all tests for real(64), uint(64)
  - PCG failed 1 test for real(32)
    - as does the C PCG implementation with the same seed

⇒ PCG offers much improved statistical properties

Random: Impact

- **PCG is faster and more flexible than NPB**
  - 1.4x when generating doubles; able to generate integers directly



Random: Impact

Status:

- PCG RNG is the new default in 1.13
- Better performance and statistical properties
- Integer output supported

Next Steps:

- Improve API based on review, user feedback, Chapel improvements
  - e.g., leader-follower improvements required to zipper RNGs naturally
- Support additional RNGs as necessary / desired

JAMA: Linear Algebra module
(contributed by Chris Taylor)

JAMA: Background and This Effort

Background:

- JAMA: Linear Algebra package originally for Java
  - Aimed at creation/manipulation of real, dense matrices
  - Developed by MathWorks and NIST
  - Ported to Chapel
- Focuses on 5 fundamental matrix decompositions:
  - Cholesky – for symmetric, positive definite matrices
  - LU – for rectangular matrices
  - QR – for rectangular matrices
  - Eigenvalue – for symmetric and nonsymmetric square matrices
  - Singular – for rectangular matrices

This Effort:

- Ported JAMA to Chapel

JAMA: LU Decomposition Example

- **Example usage:**

```
use LinearAlgebraJama;

var A = …; // Initialize A.  We'll compute L and U from A such that L*U = A
var LU = A.lu();
var L = LU.getL();
var U = LU.getU();
… // Using L and U, solve Ax = b for x given b (for instance)
```

$$\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} = \begin{pmatrix} l_{11} & 0 & 0 \\ l_{21} & l_{22} & 0 \\ l_{31} & l_{32} & l_{33} \end{pmatrix} \begin{pmatrix} u_{11} & u_{12} & u_{13} \\ 0 & u_{22} & u_{23} \\ 0 & 0 & u_{33} \end{pmatrix}$$

JAMA: Eigenvalue Example

- **Example 2:**

```
use LinearAlgebraJama;

var A = …; // Initialize A. If symmetric, V*D*V' = A
var Eig = A.eig();
var D = Eig.getD(); // an eigenvalue matrix
var V = Eig.getV(); // an eigenvector matrix
… // Using D and V, find the inverse of A (for instance)
```

JAMA: Next Steps

- **Create online documentation**
  - Current document comments are javadoc style rather than chpldoc
- **Connect to LAPACK and BLAS modules**
  - Once BLAS module routines finished
- **Design/implement sparse matrix solution**
- **Use as starting point for computer algebra module**
  - Similar to Python's Theano, NumPy
  - Aimed at dense vector/matrix computations
  - Also would make use of LAPACK/BLAS routines

FileSystem/Path Module Improvements

FileSystem/Path: Background and This Effort

Background:

- Recent releases added *FileSystem* and *Path* modules
  - *FileSystem* was nearly complete, but missing a few routines
  - *Path* was mostly empty, waiting on strings to mature

This Effort:

- Complete *FileSystem*
- Continue with *Path* now that strings are in good shape

FileSystem/Path: Status and Next Steps

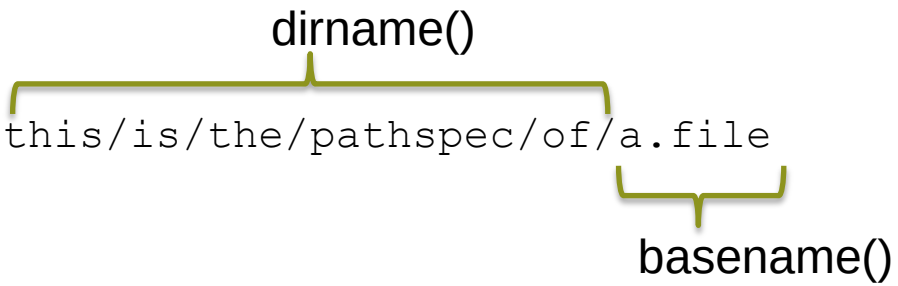
Status:

FileSystem: Finished remaining routines

- **rmTree()**: remove directory and contents
- **moveDir()**: move directory and contents to new location

Path: Added a few more routines

- **basename()**: last component of given path
- **dirname()**: all but last component of given path
- **splitPath()**: divide path into (dirname, basename)
- 10 functions remain unimplemented
  - **absPath()**, **joinPath()**, etc.



Next Steps: complete remaining *Path* routines

Spawn Module Improvements

Spawn Module Improvements

Background: Added 'Spawn' standard module in v1.12

- had a bug where *communicate()* did not function correctly
- had several bugs related to interrupted system calls
- did not include functions for sending signals to subprocesses

This Effort: Improved the Spawn module

- fixed *communicate()*
- made *wait()* optionally call it when *buffer*=true via new argument:

```
proc subprocess.wait(out error: syserr, buffer=true) …
```

- fixed problems with interrupted system calls
- added support for sending signals (contributed by Nick Park)

Impact: Spawn module is much more stable and usable

Next Steps: Write more programs using the Spawn module!

I/O Improvements for JSON

JSON Improvements: Background & This Effort

Background:

- I/O module supports *writeln*, *writef*, …
- during v1.12, there was an ongoing effort to improve JSON I/O

This Effort:

- Improved JSON support with ~ in format strings to skip fields
  - see example on following slides

Example Tweet in JSON format

- **Tweets have 34 top-level fields**
  - including nested structures containing additional fields

{ "coordinates": null, "created_at": "Fri Oct 16 16:00:00 +0000 2015", "favorited": false, "truncated": false, "id_str": "28031452151", **"entities": {** "urls": [{ "expanded_url": null, "url": "http://chapel.cray.com", "indices": [69, 100] }], "hashtags": [ ], **"user_mentions": [{** "name": "Cray Inc.", "id_str": "23424245", **"id": 23424245**, "indices": [25, 30], "screen_name": "cray" **}] },** "in_reply_to_user_id_str": null, "text": "Let's mention the user @cray -- here is an embedded url ..... http://chapel.cray.com", "contributors": null, **"id": 28039652140**, "retweet_count": null, "in_reply_to_status_id_str": null, "geo": null, "retweeted": false, "in_reply_to_user_id": null, **"user": {** "profile_sidebar_border_color": "C0DEED", "name": "Cray Inc.", "profile_sidebar_fill_color": "DDEEF6", "profile_background_tile": false, "profile_image_url": "http://a3.twimg.com/profile_images/2342452/icon_normal.png", "location": "Seattle, WA", "created_at": "Fri Oct 10 23:10:00 +0000 2008", "id_str": "23502385", "follow_request_sent": false, "profile_link_color": "0084B4", "favourites_count": 1, "url": "http://cray.com", "contributors_enabled": false, "utc_offset": -25200, **"id": 23548250**, "profile_use_background_image": true, "listed_count": 23, "protected": false, "lang": "en", "profile_text_color": "333333", "followers_count": 1000, "time_zone": "Mountain Time (US & Canada)", "verified": false, "geo_enabled": true, "profile_background_color": "C0DEED", "notifications": false, "description": "Cray Inc", "friends_count": 71, "profile_background_image_url": "http://s.twimg.com/a/2349257201/images/themes/theme1/bg.png", "statuses_count": 302, "screen_name": "gnip", "following": false, "show_all_inline_media": false **},** "in_reply_to_screen_name": null, "source": "web", "place": null, "in_reply_to_status_id": null **}**

JSON Improvements: Reading Tweet subsets

```
// define Chapel records whose fields reflect only
// the portions of the JSON data we care about

record TweetUser {
  var id: int;
}
record TweetEntities {
  var user_mentions: list(TweetUser);
}
record User {
  var id: int;
}
record Tweet {
  var id: int,
      user: User,
      entities: TweetEntities;
}
```

```
proc process_json(…) {
  var tweet: Tweet;

  while true {
    // "%~jt" format string:
    //    j: JSON format
    //    t: any record
    //    ~: skip other fields
    got = logfile.readf("%~jt",
                        tweet,
                        error=err);
    if got && !err then
      handle_tweet(tweet);
    if err == EFORMAT then ...;
    if err == EEOF then break;
  }
```

JSON Improvements: Impact and Next Steps

Impact:

- JSON support is improved in version 1.13

Next Steps:

- Support formatting extensions to *channel*
  - since not all formats will be supported directly as JSON is

Other I/O Improvements

Other I/O Improvements

- **HDFS package now supports libhdfs3**
  (contributed by Chris Taylor)
- **Removed *Reader* and *Writer* types in favor of *channels***
- **Made *readbits*/*writebits* accept any integral argument**
- **List module now supports JSON format**
- **Default I/O routines now ignore 'param' fields**
- **channels now support an isClosed() method**

Other Library Improvements

Other Library Improvements

- **Time.sleep() now optionally supports a unit argument**
  (contributed by Nick Park)
- **exit() can now be called without arguments**
  (contributed by Kushal Singh)
- **Also, aforementioned library routines for strings:**
  http://chapel.cray.com/docs/1.13/modules/internal/String.html

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